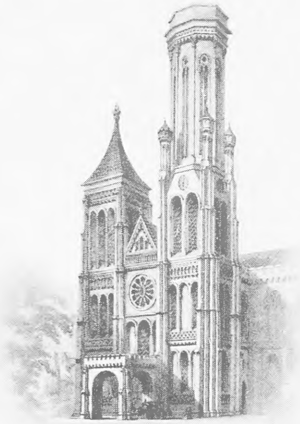
PASSENGER PIGEON



THE CONDUCTION OF RESEARCH

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RESEARCH may be defined as the process of intentionally looking for something new; the value of some physical constant, a new material, or a method of performing some operation. According to its purpose, research can logically be divided into two classes; the first is pure research which includes the study of the properties of natural objects, such as the determination of atomic weights, the distance of a star, or the development of plants and animals, while the second may be termed industrial research which includes the development of a material having commercially useful properties, or the refinement of a process so as to increase its output or decrease its cost. Such a division can not of course be strictly held to, for the two classes intermingle at times, as there are a great many cases where an investigation, starting as pure research, later developed industrial possibilities. In fact there are very few pieces of pure research that do not sooner or later offer valuable contributions to the industries.

A very large portion of the modern development in science is due to systematic research. While it may be true that some highly interesting facts are stumbled upon in the realm of science, it is the thorough, painstaking investigations conducted at our government, university and industrial laboratories that in the last twenty years have given us such a remarkable insight into the structure of matter and the universe.

Engineering, which has in the past, clung to cut and try methods, is beginning to realize the value of trained men and well-equipped laboratories in solving its problems. Perhaps no division of engineering has advanced as rapidly in this respect as aeronautics, comparatively a very new subject, and yet, because of its exacting demands, has caused the development of methods so advanced that they may well be borrowed by the older branches. Commercial enterprises of all types are developing research by organizing their own laboratories or by financing the research laboratories of the universities. Many concerns are devoting five to ten per cent. of their profits to research, and some have laboratories employing scores of trained men. The industrial research laboratory is past the experimental stage and is recognized as a sound financial asset.

Research may also be divided according as it is definite or indefinite, that is, whether or not it is known beforehand what is being

searched for. An example of the first class would be the determination of the melting point of an element, while the development of a machine for making bricks belongs to the second. The first class is the more straightforward, so that the program can be planned in advance with the possibility of only minor changes, and the final result will be uncertain only in its degree of accuracy. A research of the second class is more difficult, as it is a process of trial and error, the most hopeful ideas being tried out until by the knowledge gained from previous failures, a successful result is obtained. But, unfortunately, in this class of research a successful result can not be guaranteed in advance, and consolation must sometimes be obtained by the knowledge that a well tried failure is a step ahead.

Perhaps the first thing to do when commencing a piece of research is to make a thorough study of the available literature on the subject; first, to get new ideas, and, second, to prevent the repetition of methods that have been found unworkable. On the contrary, there are certain types of original thinkers who claim that they do not wish to know what any one else has done on the subject, as they believe that this knowledge will hamper the freedom and originality of their work. This manner of working certainly leads to much needless duplication and is not to be recommended except for very special cases. It is unfortunately true that many statements appearing in print are in error, due to poor experimentation, wrong conclusions and arithmetical blunders, and it is strange how long these erroneous statements are accepted. There are many instances where results of this type have been quoted several times by other authors before their absurdity has been made evident. It is, therefore, advisable to take all information on trial, and to take no one's statements for granted without giving them a thorough examination.

After all the important information has been reviewed and carefully analyzed, a plan, or several alternative plans, can be laid out for the most promising manner of attacking the given problem. Although the plan will undoubtedly have to be revised or even completely changed during the progress of the investigation, it is much better to have a definite program to start with than to work along in a haphazard manner, principally because of the training gained by the experimenters in an orderly procedure. It is foresight and anticipation of difficulties at this time that saves endless complications later on, and the value of a research director depends on his ability to keep his men from getting into trouble, or, if this is impossible, to get them out as quickly as possible. The more experience one has had in research the more clearly can he visualize the subsequent procedure, and the final results.

If the research being undertaken is of a simple character the only

apparatus needed will be of a standard type that can be readily obtained, but in most cases it will be necessary to build special apparatus. There are two ways to design research apparatus; the first, is to lay out an expensive and elaborate design on the drafting board without experimental trial of any of its parts, the second, is to carry on the experimental work as far as possible with inexpensive, temporary means, until the soundness of the method is assured, and then designing the apparatus from the knowledge gained in this manner. The first method may work out satisfactorily but more often it does not, and an expensive instrument or machine must be greatly altered or scrapped. The second is not as rapid nor as convenient, but it is safe and sure and should certainly be used unless there is a large fund of past experience to draw from in regard to that particular subject.

After the general type of apparatus is decided upon, there is its detailed construction to consider. If it is to be used for only a short time, there is no need to go into elaborate design, or neat finish; the main points to think of are cheapness and quickness of construction and ample opportunities for making alterations. It is always best to rebuild a standard type of machine if possible, and it is surprising how a little ingenuity will make a working device out of the most common parts. It is natural that an experimenter should desire to have an original and neat piece of apparatus, but first it should be determined whether the increased efficiency in operation will warrant the necessary expense. However, it is often the case that a little extra expense if applied efficiently to finishing a piece of apparatus will effect a saving in the end by preserving it from the attacks of moisture or chemical fumes. At the same time a well finished job, even though it will not actually give more accurate results, takes it out of the home made class, and gives to the report illustrated by its photographs, a workmanlike tone that is of the greatest value in raising the standard of that particular investigation. Although an expensive and well finished instrument does not assure excellence in the experimental work, yet the person reading the report is unconsciously affected by the appearance of the apparatus, crude apparatus being associated with uncertain results. On the other hand, there is undoubtedly a tremendous amount of money spent each year on unnecessarily elaborate machines and instruments, but the waste is usually due more to the fact that the complete design is unworkable, than that the elaboration is unnecessary.

There are other types of research that extend indefinitely into the future, using principally the same apparatus in all the tests. Examples of this are tests of material strength, or model testing is towing basins or wind tunnels. In these cases the conditions are far different from the isolated investigation, and it is simply a question of how far it will be advisable to go, in using automatic and recording devices to reduce

the personnel required in the testing. For example let us consider a wind tunnel balance for measuring three forces and three moments on an airplane model. Ordinarily two men operate the balance, reading two of the required quantities at a time. If it were a question of time, the balance might be arranged to use six observers who would read the six quantities simultaneously, but this would increase the operating expenses. The next improvement would be an automatic balancing arrangement so that one observer could record all six quantities, but this would require a much more expensive balance. If it was desired to reduce the labor still further, the work of several draftsmen could be dispensed with by making the balance record and plot all six quantities, a process that is actually quite simple to do, but which would require still more additions to the balance. The elaborateness of a piece of apparatus, then, will depend largely on how much it will be used, for there would obviously be no use in building an expensive and labor saving machine for a few experiments, nor would it be economical to use a cheap and inconvenient machine for an extended series of investigations.

Another particular that should be kept in mind when designing apparatus is a construction that will make the calculation of results simple and convenient. It very often happens that a small change in an otherwise excellent instrument will save days, and perhaps weeks of computation. As an example of the importance of this, it may be stated that in a certain investigation on an airplane in free flight, the data was collected in less than ten hours of flying, but required the time of three men for four months to work up the final results, and there are other experiments where the ratio is even greater than this.

The economy of having a well equipped research laboratory is soon demonstrated by the saving in time and expense in setting up for an experiment, and the older a laboratory is the more apparatus there is accumulated from which to select. In any experimental work a large junk pile is invaluable, and until this is collected, the true experimenter cannot work efficiently. The laboratory should have a shop of its own, or immediate access to one, equipped to do the class of work desired, as the ability to easily get small parts constructed or alterations made is of the greatest importance in the efficient conduction of research. Nearly all classes of research require in some way the application of photographic methods, so that a dark room is a valuable, sometimes a necessary adjunct to the laboratory.

With the construction of the apparatus completed, we come to the actual carrying out of the research. The first thing to do is to set up and try out the apparatus and to determine with what accuracy the results may be depended upon. It is good policy, especially in extended experiments, to take plenty of time in the beginning to get all

parts in reliable operation, or much time and accuracy will be lost later on by breakdowns. Often times a slipshod arrangement is allowed to stand with the hope that it will hold together during the test, but nothing can be more discouraging than to find at the completion of a long run that some little thing had gone wrong and rendered the results useless.

Perhaps it would not be out of place at this time to touch on the subject of precision of measurements. It is believed that a lack of understanding of this subject leads to a large amount of extra work being done, and accuracy sacrificed, in many branches of research. There is obviously no use in obtaining data, or of computing results, to a much higher degree of accuracy than the least precise component, and it is the neglect to find the precision measure of this component that leads to much needless computation. On the other hand, it sometimes happens that if the least precise component were recognized it could be obtained with greater precision, thus increasing the accuracy of the whole experiment. It often happens, too, that certain factors having only a slight influence on the results, are either recorded when their effect is smaller than the errors in the other factors, or they are neglected when that effect is larger than the errors introduced from all other sources. For this reason, every condition that can in any way effect the final results, should be carefully analyzed, not only to determine whether it can safely be neglected, but to find out how closely it need be measured if it can not be neglected.

The successful carrying out of an experiment requires the constant checking up of the data obtained, in order to detect an error before it has invalidated a long series of runs. It is only by constant vigilance that errors can be excluded from the work, and it is the ability to detect irregularites that will cause future errors, or to detect the errors themselves before they can cause trouble, that distinguishes the true experimenter. For example, let us consider a certain test to determine the effect of varying the aspect ratio of a model airplane wing in the wind tunnel. The procedure consisted in making a test, then cutting off a small length of the wing, and repeating the test, continuing the process until the span of the wing was reduced to a small amount. It would be extremely unwise in an investigation of this kind to collect all of the values without working up the data and constantly comparing it with the preceeding results each time before cutting off the wing. Otherwise, it might be found that one or more of the runs did not agree with the rest, due to a lack of alignment or to some other type of error that is apt to creep into any experimentation. After the wing had been cut down, however, it would be too late to make a check run and the whole test would be invalidated or at least made to appear of doubtful value.

Before beginning an experiment care should be taken that everything is functioning properly, and that all disturbing factors have been taken into account. Never take a chance, as every research man should realize that not only his reputation, but that of the organization with which he is connected, is endangered by his mistakes, and he should under no conditions allow results to come from him, unless he is very sure of their correctness.

It might seem unnecessary to bring up the subject of honesty in research, for there would seem to be very little reason to give results deliberately in error. It has often happened, however, that an experimenter has shaded the values of his readings to make them come closer to what he supposed was the true value, but he often finds later, that he has gone in the wrong direction, and readings taken in this way will give neither the true mean nor the probable error. Sometimes this squeezing of results up or down is done quite unconsciously, and for this reason when it is desired to make a check run, the results of the first run should never be in sight, or it will not be a true check, even though the recorder is not in any way intentionally dishonest.

When it is desired to determine the accuracy of certain data, or to be assured that it lies within the permissible limits of accuracy, it is customary to make two or more runs under identical conditions, the difference between the values obtained in each being an indication of the accuracy that may be expected. This does not, however, tell the whole story, as it does not take into account those errors in the design or setting up of the apparatus, or the individualities of the experimenters. For this reason, it is always well when making a check run to reset the apparatus or, better, to use a different piece of apparatus and different observers, in which case the results may be considered to give a true indication of the probable error from all sources. It often happens that a certain set of facts are not obtainable in a direct or simple manner, nor is the best method that can be devised entirely satisfactory. In such cases it is always best to obtain the results in several different ways, and, although none of them may be satisfactory, yet, if the several results show an agreement, it may be concluded with certainty that they are correct. Even in the more straightforward investigations, wherever possible, the results should be checked up by an alternative method, as this is an excellent way to make others have confidence in the data.

Next to accuracy, the most important consideration in research is efficiency, that is, the obtaining of the largest amount of results for the least expenditure of time and money. Efficiency can only be attained by the careful laying out of the work, the careful determination of what is necessary to do to get the required accuracy, and, most important, to have a smooth running organization. The laying out of the

work consists in ordering materials, having apparatus designed and constructed and deciding on the methods to be used. The laying out of the work in a manner to promote efficiency depends largely on the foresight and experience of the experimenter or research director. For this reason, it is false economy to employ low grade or inexperienced research men, as the saving in the pay roll is more than offset by the decreased value of the results and the increased cost of the investigation.

As time is usually as important an item in efficiency as cost, the ordering of necessary supplies should be accomplished as early as possible, and when big delays are impossible to avoid because of the lack of some material, it may become necessary to alter the experimental methods in order to be able to proceed within a reasonable time. It is very costly to have everything set for performing an experiment, and then to find that some small but vital thing has been forgotten which will take weeks to procure. All phases of the preliminary work should be constantly checked over and the most delaying items followed up vigorously.

The previous discussion of efficiency has been confined to a single piece of research, but usually a number of investigations are going on together in one laboratory, perhaps a separate group of men working on each research, or a group alternating between several types of work as conditions permit. In this case it is the duty of the research director to arrange the work not only so that every one will be kept busy, but so that each man will be working to the best advantage. Every one is more or less of a specialist, and it is of considerable advantage to have each person kept as far as possible on one type of work. This can not, of course, always be done, but by carefully laying out the work ahead in this respect, it will be possible to have the men working in their most efficient positions a large part of the time. The same thing applies to pieces of standard apparatus such as balances, testing machines, etc., so that the work should be planned to use the equipment as efficiently as possible.

In regard to the selection and training of the research personnel, it will be best to first discuss the types of men available, exclusive of their particular training. In the first place men may be divided rather sharply into two classes, the first we will call practical, and the second, theoretical. The first class have mainly gained their knowledge from experience, are mechanically inclined and know how to use their hands, while the second class have obtained their knowledge almost exclusively from books and have very little commonsense in regard to mechanical matters. For example, one of the theoretical class may be able to make a complex computation of the stresses in a certain small bolt, and yet when screwing in the same bolt he will calmly twist its head off, simply because he has no mechanical sense. The latter are a type that

are of great value in mathematical work, computations and the writing of reports, but when it is attempted to use them on purely experimental work, their efficiency is greatly reduced. It is far easier to teach one of the practical class to work efficiently on theoretical problems, than is to teach one of the theoretical class to work efficiently with their hands. It is quite necessary to have experimenters who can be trusted with delicate apparatus without having constantly to fear for its safety.

Some men are naturally hustlers and possess initiative enough to make themselves of value with very little supervision, and some go so far in this direction as to require constant restraint to keep them from getting beyond their depth, but this quality is on the whole a good one, and should be directed rather than discouraged. On the other hand, there are men who will take no responsibility and need constant pushing to keep them working efficiently, but wherever possible it is better to lead than to force. If a person is really interested in his work, and by interested, I mean the ability to derive pleasure from thinking of the problems evolved outside as well as inside of working hours, he requires no pushing and very little directing, so that the whole problem of successful administration lies in getting the staff interested in the problem on which they are working.

As far as possible it is best to give to each man a definite job, and make him responsible for it; giving him the credit when it is successfully completed. This stimulates interest and originality, and is much better than a constant supervision down to the smallest details, a method that is likely to produce ill feeling and retard the development of the experimenter. Of course, an inexperienced man can not be efficiently put on to a new subject without considerable supervision, but this supervision should be instructive rather than destructive, and as soon as he shows himself capable of handling the work he should be left to carry on alone. When, as is often the case, a number of men are working on one problem each one should be encouraged to acquaint themselves with the work of the others in order to obtain a more general view point.

It often happens in research work that certain portions of it, such as computations, are exceedingly monotonous and it would certainly be an injustice to give all of this portion to one man, so that it is always best to distribute this kind of work among the investigators, unless, of course, some of the men are especially hired for this, and have no experience fitting them for other work. There are some types of research that can be most efficiently carried out by a single person working exclusively on that job, but in the majority of cases it is better to concentrate a number of men on the problem, not only to finish it up and get it out of the way quickly, but because a man is apt to get into a rut when working alone. There are some experiments that require a high

degree of manipulative skill and to these should be assigned the type of man who is naturally handy with his hands. Conversely there are problems of a mathematical nature that would be exceedingly irksome to the preceding type, whereas the theoretical type could handle them efficiently. It is the problem, then, of the research director to so arrange the work that each man of his staff will be working to the greatest advantage.

Undoubtedly the most important quality that any experimenter can have is persistence. There are many problems that require months and perhaps years of hard, discouraging work before the first ray of success can be discerned, and in such cases it requires the utmost faith in the ultimate result to enable one to keep up his interest. It is only by the careful, systematic elimination of each obstacle as it comes up and the direction of the work continually into new and more promising channels that will make successful what to the less determined experimenter would be a failure.

Perhaps it will not be out of place to say a few words about the presentation of results. In the first place, the data should be given, wherever possible, in graphical form. There are some instances where the accuracy of the results is greater than can be represented by a plot, in which case the data must be also given in tabular form, but in most cases a curve is sufficient and the tables may be omitted. When plotting curves, no points should be used except those directly computed from the experimental results, as the practice of some very reputable laboratories of taking points from a faired curve as the basis of plotting is very misleading as to the regularity of the results. On the other hand, no experimental curve should be shown without including the actual points, otherwise the results can not help but be regarded with suspicion. It is always better to present a few well checked results than a multitude of irregular ones.

One of the secrets of experimentation is to know when to stop, for it is a natural tendency to carry the work further than the value of the additional results will warrant, and it is inefficient to allow a nearly finished piece of research to drag along. There is of course, no definite point where a piece of work can be considered finished, and often times one feels that he is in a position to efficiently commence the work only when the allotted time or money is exhausted. For this reason one of the most important functions of an investigation should be the paving of the way for more extended work. Therefore every report should contain an account of the difficulties encountered, and most important the recommendations of the experimenter for the conduction of further research, for every difficulty, and every failure, should be made of value by preventing others from encountering the same obstacles.

It is urged that every investigation that produces results of interest

or value be published or in some way be made available to those who are interested. It now happens, especially in the industrial laboratories, that much work is done which is never known outside, and there is generally no reason why the results should not be published after the particular organization has received its benefit. Because of this practice a great deal of money is spent in duplicating work that has been already accomplished, and, while a certain amount of duplication is valuable as a check, it is in general very uneconomical. In the same way, it sometimes happens that similar investigations are undertaken simultaneously, and, although their results are later published, it means an unnecessary duplication. In this particular it would be of great value to have a research clearing house where all the work in preparation could be gathered together for general information.

It may be stated in conclusion that the carrying out of a piece of research will comprise in general the following procedure: First, the similar work of others is studied, especially their difficulties and failures, and from this information a plan of operation is laid out. And if there is any doubt, and there usually is, as to the practicability of the proposed methods, preliminary experiments should be conducted, from which data are obtained for use in designing apparatus and for more completely planning the subsequent procedure. In carrying out the actual work, the first consideration should be accuracy and the second, efficiency, both depending on suitable equipment and on an interested and well-organized staff. Lastly, the experimenter must organize his results, and deduce from them conclusions that will be of value in joining them with similar work and in advancing the theory and practice of the subject. Briefly, successful conduction of research depends on the foresight and vision of the experimenter in laying out the work, his accuracy, persistence and manipulative skill in carrying it out, and, lastly, his analytical ability in deducing conclusions from the results.